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Double Suppression of FCNCs in a Supersymmetric Model [a]

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ABSTRACT

A concrete model which can suppress FCNCs and CP violating phenomena is suggested. It is an S_3 symmetric extension of the MSSM in extra dimensions, where only $SU(2)$ and $SU(3)$ gauge multiplets are assumed to propagate in the bulk. They are suppressed due to S_3 flavor symmetry at M_{SUSY}, and the infrared attractive force of gauge interactions in extra dimensions are used to suppress them at the compactification scale. We find that $O(1)$ disorders of the soft parameters are allowed at the cut-off scale to suppress sufficiently FCNCs and CP violating phenomena [1].

1. Introduction

In a Minimal Supersymmetric Standard Model (MSSM), the soft SUSY breaking terms contain more than 100 parameters in general. These parameters can induce dangerous Flavor Changing Neutral Currents (FCNCs) and CP violating phenomena, which should be strongly suppressed. If these parameters approximately satisfy the conditions called universality or alignment, these phenomena are suppressed. The problem of how and why the soft SUSY breaking terms satisfy these conditions is called the SUSY flavor problem.

There are several theoretical approaches to overcome this problem. We will present a model with S_3 flavor symmetry which is embedded into 5 space-time dimensions and show that our model can soften the SUSY flavor problem.

2. S_3 Symmetric Model in $D=4$

We give a brief review of our model at first [1,2].

We consider the S_3 flavor symmetric extension of MSSM with additional Higgs doublets. In our model, there are 3 "generations" of the Higgs doublets and they belong to $\mathbf{2}+\mathbf{1}$ representations of S_3 which is the same as the matter fields ;

$$\begin{array}{lcl} \mathbf{2} & ; & Q_I, U_{IR}, D_{IR}, L_I, E_{IR}, N_{IR}, H_I^U, H_I^D \quad (I=1,2) \\ \mathbf{1} & ; & Q_3, U_{3R}, D_{3R}, L_3, E_{3R}, N_{3R}, H_3^U, H_3^D. \end{array} \tag{1}$$

The S_3 invariant Yukawa coupling for up-quark sector is ;

$$\begin{aligned} W_U &= Y_1^U Q_I H_3^U U_{IR} + Y_2^U f_{IJK} Q_I H_J^U U_{KR} + Y_3^U Q_3 H_3^U U_{3R} \\ &\quad + Y_4^U Q_3 H_I^U U_{IR} + Y_5^U Q_I H_I^U U_{3R}, \\ \text{where}\quad f_{121} &= f_{211} = f_{112} = -f_{222} = 1\ ,\ \text{others} = 0, \end{aligned} \tag{2}$$

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and similar for the other sectors.

When the electroweak symmetry is broken under the assumption $< H_1^{U,D} >=< H_2^{U,D} >$, the mass matrix for each sector becomes

$$\mathbf{M}_a = \begin{pmatrix} m_1^a + m_2^a & m_2^a & m_5^a \\ m_2^a & m_1^a - m_2^a & m_5^a \\ m_4^a & m_4^a & m_3^a \end{pmatrix} \quad , \quad a = u, d, e, \nu. \tag{3}$$

From the mass matrices, we can find a consistent set of mass parameters which reproduce the realistic masses and the mixings.

Since both the scalar mass terms and the A-terms are S_3 invariant, the conditions universality and alignment are partly realized and these have the form

$$\begin{aligned} \tilde{\mathbf{m}}^{\mathbf{2}}_{aLL(RR)} &= m_a^2 \begin{pmatrix} a^a_{L(R)} & 0 & 0 \\ 0 & a^a_{L(R)} & 0 \\ 0 & 0 & b^a_{L(R)} \end{pmatrix}, \\ \tilde{\mathbf{m}}^{\mathbf{2}}_{aLR} &= \begin{pmatrix} m_1^a A_1^a + m_2^a A_2^a & m_2^a A_2^a & m_5^a A_5^a \\ m_2^a A_2^a & m_1^a A_1^a - m_2^a A_2^a & m_5^a A_5^a \\ m_4^a A_4^a & m_4^a A_4^a & m_3^a A_3^a \end{pmatrix}. \end{aligned} \tag{4}$$

We can explicitly calculate the parameters δ which are the off-diagonal elements of the soft terms in the super-CKM basis by using the mixing matrices obtained from (3). The parameters δ are defined as

$$\delta^a_{LL(RR)} = \frac{U^\dagger_{aL(R)}\ \tilde{\mathbf{m}}^{\mathbf{2}}_{aLL(RR)}\ U_{aL(R)}}{m^2_{\tilde{a}}} \text{ and } \delta^a_{LR} = \frac{U^\dagger_{aL}\ \tilde{\mathbf{m}}^{\mathbf{2}}_{aLR}\ U_{aR}}{m^2_{\tilde{a}}}, \tag{5}$$

where $m_{\tilde{a}}$ is the average sparticle mass.

We can obtain the conditions for the soft parameters $\Delta a \equiv b - a$ and $\tilde{A}_i - \tilde{A}_j$ ($\tilde{A}^a \equiv A^a / m_{\tilde{a}}$) by comparing these δ's with the experimental constraints[3] at M_{SUSY}. The results are ;

$$\begin{aligned} \tilde{A}_2^\ell - \tilde{A}_2^\ell &\sim O\left(10^{-1}\right)\ ,\ \mathrm{Re}\left(\tilde{A}_i^d\right) - \mathrm{Re}\left(\tilde{A}_j^d\right) \sim O\left(10^{-2}\right) \quad (i, j = 1 \sim 5)\ , \\ \left|\mathrm{Im}\left(\tilde{A}_1^u\right)\right| &\sim O\left(10^{-4}\right)\ ,\ \left|\mathrm{Im}\left(\tilde{A}_3^u\right)\right| \sim O\left(10^{-2}\right)\ , \\ \left|\mathrm{Im}\left(\tilde{A}_1^d\right)\right| &\sim O\left(10^{-3}\right)\ ,\ \left|\mathrm{Im}\left(\tilde{A}_3^d\right)\right| \sim O\left(10^{-2}\right)\ , \\ \Delta a_L^u \Delta a_R^u &\sim O\left(10^{-1}\right)\ ,\ \Delta a_L^d \Delta a_R^d \sim O\left(10^{-2}\right)\ ,\ \Delta a_L^\ell \sim O\left(10^{-2}\right), \\ & \text{and others} \sim O(1). \end{aligned} \tag{6}$$

It still needs a fine-tuning for the soft parameters despite the suppression by S_3 symmetry.

3. Extended Model into $D = 5$

Next, to soften the conditions (6) at M_{SUSY} we consider a 5 dimensional model[4] with orbifold compactification.

Let $SU(2)$ and $SU(3)$ gauge fields be the bulk fields and matter and $U(1)$ gauge fields be the brane fields. We assume that the zero modes of the bulk fields consist of the previous 4 dimensional model by some appropriate parity assignment. The renormalization group equations (RGEs) for the ratio of the soft parameters and the gaugino mass have the infrared fixed points, and it converges to the fixed point by the power-law running. Moreover the convergence is originated by the gauge interaction which is flavor blind. Therefore the value at low energy scale is independent of the initial values at the cut-off scale Λ and it is independent of the flavor, too (Fig. 1 and Fig. 2). More precisely, it can

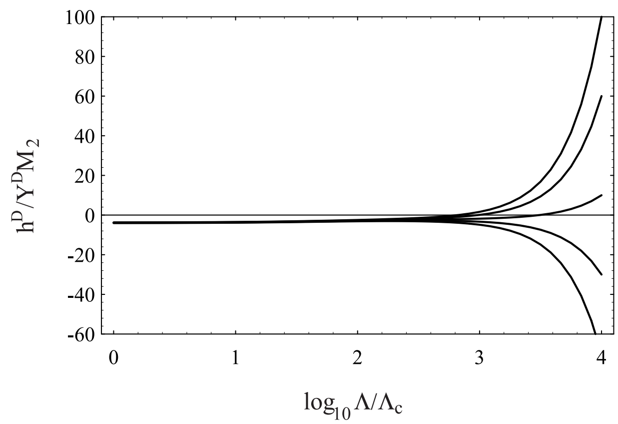

Figure 1: Infrared convergence of the A-term.

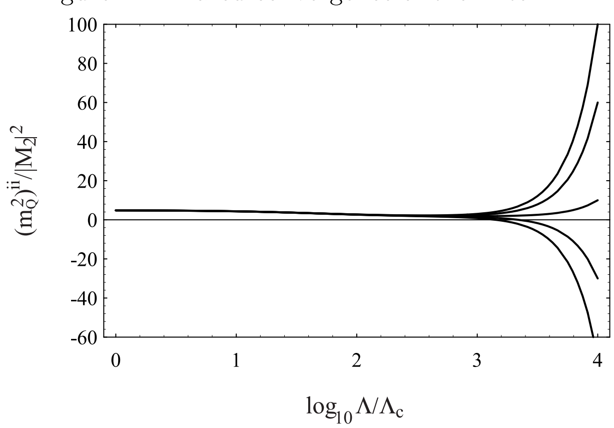

Figure 2: Infrared convergence of the scalar mass.

be found that the disorder of the soft parameters at the compactification scale ($\Lambda_C \sim M_{SUSY}$) becomes smaller than that at the cut-off scale :

$$\left(\frac{m_{\tilde{a}}^2\ \Delta a^a}{M_2^2}\right)^{1/2}\ ,\ \frac{A_i^a - A_j^a}{M_2}\ \sim\ O(1)\ \text{ at } \Lambda\ \rightarrow\ 10^{-2}\ \text{ at } \Lambda_C\ (\sim M_{SUSY}\ \sim\ 10^{-4}\Lambda), \tag{7}$$

where M_2 denotes $SU(2)$ gaugino mass.

We have to mention the reason why the figures are drawn in the range from $\Lambda \sim 10^4\ \Lambda_C$ to Λ_C, where Λ_C denotes the compactification scale of the fifth dimension. The RGE for the soft mass of the scalar partner of the right-handed charged lepton (say $m_{E_R}^2$) depends

only on the brane-localized $U(1)$ gauge field. It means that $m^2_{E_R}$ runs logarithmically even in the range above Λ_C while the gaugino mass decreases in power-law. The cut-off scale has been determined by the assumption that the ratio $m^2_{E_R}/M^2_2$ satisfies the relation

$$\frac{m^2_{E_R}}{M^2_2}(\Lambda_C) \sim 10^{-1}\ ,\ \frac{m^2_{E_R}}{M^2_2}(\Lambda) \sim 10^{+1}. \tag{8}$$

From the condition (8), the cut-off scale Λ can be taken at most to be $\Lambda \sim 10^4\ \Lambda_C$. Because of the power-law convergence of the soft masses, the conditions (6) can be softened at Λ, and from the precise estimation, we found that $O(1)$ degeneracies of the soft terms at Λ are necessary to satisfy the condition (6) at M_{SUSY}.

4. Conclusion

We have presented a model which is S_3 symmetric extension of MSSM. The conditions for the soft terms to suppress FCNCs are still severe at M_{SUSY} despite the suppression by S_3 symmetry. However, at the cut-off scale Λ, $O(1)$ disorder of the soft parameters is allowed, because the infrared convergence by power-law running additionally helps realizing universality and alignment of the soft parameters.

5. References

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